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# Passive control of indoor climate conditions in low energy buildings

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**Abstract**

A few features of building envelope that intensively affect summer internal microclimate in low energy building have been analyzed in presented paper. It was suggested to call those features "the passive means of protection against overheating". Adaptive comfort method was used as a criterion of internal conditions evaluation. Dynamic thermal simulations of building model were conducted in EnergyPlus software. The main aim of this study, closely related to European Energy Directives, is to identify ways and means how to avoid mechanical cooling of building, connected with increased demand on energy, and in the same time to safeguard comfortable indoor climate. The basic conclusions regarding passive measures of protection against overheating have been presented.

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*Keywords:* low energy building; overheating; adaptive thermal comfort;

## 1. Introduction

The term "passive buildings" has now become the readily used and even fashionable slogan. However, few people associate that this name was originally related to passive solar systems and was invented and introduced already decades ago [1]. Passive solar system is present in each building, without any exception, if there is only a glazed opening. During the summer or even transition periods excessive solar gains may result in unbearable overheating and their removal would be associated with a significant contribution of energy [2]. While the passive solar energy use strategy is nowadays better known and understood, protection of the building against overheating is usually left to the final stage of the design process or even completely disregarded. Meanwhile, there are various possibilities to eliminate risk of overheating totally or at least reduce cooling load, to reduce power of installed

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cooling devices and cooling energy input [3]. The whole set of the simple measures, based on architectural or structural solutions can be called a passive method of overheating protection. This approach allows to avoid unnecessary demand on energy, as suggested in EPBD, and in the same time to maintain expected high quality of indoor environment [4].

**Nomenclature**

| | |
|---|---|
| $U_g$ | thermal transmittance of glazing ($W/(m^2 \cdot K)$) |
| $\lambda$ | thermal conductivity ($W/(m \cdot K)$) |
| c | specific heat ($J/(kg \cdot K)$) |
| $\rho$ | apparent density ($kg/m^3$) |
| E | heating demand ($kWh/(m^2 \cdot year)$) |
| EC | cooling demand ($kWh/(m^2 \cdot year)$) |
| $R_{w/f}$ | window to floor area ratio |

## 2. Assumptions of the simulation model and the adaptive comfort criterion

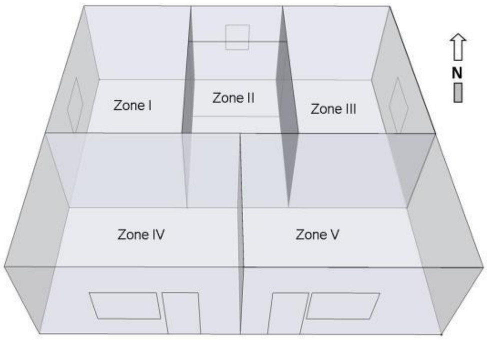


Fig. 1. View of the simulated object

Analysis of the impact of the selected design solutions on internal microclimate in modeled building, Fig. 1, was carried out by means of the software EnergyPlus.

Table 1. Characteristics of the materials

| Material | density [$kg/m^3$] | thermal conductivity [$W/(m \cdot K)$] | specific heat [$J/(kg \cdot K)$] |
|---|---|---|---|
| solid brick | 1800 | 0,77 | 1000 |
| reinforced concrete | 2300 | 2.3 | 1000 |
| thermal insulation | 15 | 0.043 | 1450 |
| lime plaster | 1601 | 0.726 | 840 |
| cement plaster | 1858 | 0.692 | 840 |
| wood | 800 | 0.22 | 2510 |
| screed | 2000 | 1.1 | 840 |

The basic version of the simulated object had the massive brickwork and the reinforced concrete building structure. Walls: internal lime plaster of 2 cm, 25 cm solid brick, 15 cm standard thermal insulation and 2 cm of external cement plaster. Internal walls: 12 cm of brickwork and two lime plasters of 2 cm each. Floors: wood 2.5

cm, 4 cm screed, soundproofing insulation of 3 cm, 12 cm reinforced concrete. Windows and balcony doors double or triple glazed, glass with low emissivity coating.

External climatic conditions for Krakow, Poland, in form of TMY weather data. Heating demand was calculated for the following months: September to May, adopted summer simulation period covers the three months: June, July and August. Heat gains in the analyzed object derived from: 4 people engaged in near sedentary activity, including their full presence at night and partial during the day, from electric equipment and artificial lighting.

Adopted method of internal microclimate assessment is adaptive thermal comfort criterion according to ASHRAE Standard 55-2013 [5, 6]. Microclimate rating associated with adaptive comfort is based on the observed in practice gradual adaptation of building user to high temperature conditions in buildings without mechanical cooling. Due to natural human adaptation mechanism, discomfort conditions occurring in cool season could be regarded as acceptable during the hot season of the year. The degree of adaptation is strictly associated with the user's ability to modify internal environment, eg. open or shade windows, use fans or even forced ventilation, match clothing etc. [6]. Such measures are available in the simulated building but not considered in the conducted simulations.

The approach used in the ASHRAE method is similar to the solution adopted in the European Standard EN 15251 [7]. Adaptive thermal comfort criterion is in this paper used as a main tool to compare and evaluate the analyzed options. An important practical advantage of using this approach in the Energy Plus simulations is the fact that the program comes with the option of counting discomfort duration, i.e. number of hours with internal operative temperature beyond adaptive comfort range for two user acceptance levels: 90% and 80% [8].

## 3. Window sizing

Decisive influence on internal conditions in buildings during the summer belongs undoubtedly to windows. Therefore it can be stated that reasonable window sizing decision at initial building design stage is the first one and very significant passive measure of passive control of indoor climate. This measure does not demand any extra investment cost or energy to run, on the contrary it may decrease costs and demand on energy.

Window size, orientation, inclination, transmission properties of the glazing, external and internal shading finally shape the room heat balance and consequently the interior microclimate [3]. This statement looks quite trivial, but it is not taken into account when making basic architectural decisions. It is worth noting that the rational design of glazing area is not possible without the use of advanced computer tools. It is because of the difficulties associated with the mathematical description of dynamic thermal phenomena but also because of the interconnection between climate, building shell thermal resistance, its heat capacity and properties of glazing.

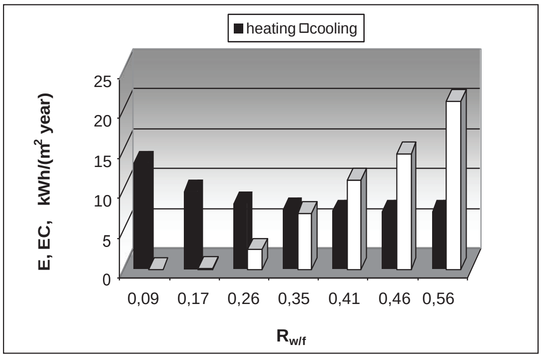


Figure 2. Zone IV. Heating and cooling demand versus south glazing area, LE triple glazing

In Fig. 2 interrelation between yearly demand on heating and cooling energy and area of south oriented window was shown [2]. In case of the very well insulated building with constant ventilation intensity, heat recovery system and triple spectrally selective glazing, optimum window area for south oriented zone is equal to 26 % of floor area. Oversized window area would result in demand on cooling much higher than in case of heating. The presented above results are case sensitive, i.e. true only for the specified part of the simulated building, ventilation profile, number and features of glazing, enclosure thermal resistance etc..

Computer simulation tool allows to assess a proposed system, but also to search for optimum solutions because of the total energy consumption and thermal comfort. The author in his previous work [3] undertook attempts to create relatively simple designing rules on the basis of computationally intensive simulations. The basic conclusions of the previously published studies:

- rational design process of glazed area cannot be based only on intuition or aesthetic emotions,
- while there are thousands of glass types with ultimately different features and they can be further combined in multiple glazing sets, traditional designing approach of binding area of a window with unspecified properties and its orientation with space floor area does not make any sense,
- glazing dimensioning cannot be based solely on heating needs, but on the total demand on heating and cooling,
- rational window area is highly dependent on: glazing properties (so there is no general rule for all the types of windows),
- it is also dependent on protection measures against excessive sunlight, lighting requirements, properties of the building envelope, but also on a way of building use and internal gains.

In Polish building regulations the simplified requirements regarding allowable maximum window area may be easily found, however they are often ignored in design process and in the formal process of application for building permit. Entirely glazed buildings may be nowadays frequently encountered in our cities.

For the further investigation it was assumed that windows are double glazed and glazing ratio (glazed area referred to the surface of the floor) of zones IV and V was taken as 17.2%, Fig. 1.

## 4. Night cooling and thermal insulation

No special research is needed today to prove the benefits of night cooling, i.e. increased intensity of the (forced or natural) air exchange during the night. In a massive building significance of night cooling goes far beyond instantaneous temperature reduction and may be used to decrease efficiently cooling load during the next day [9]. Although forced ventilation is not longer a passive measure and it is connected with extra conventional energy consumption, its advantages overcome deficiencies. Night cooling will be further treated as a basic requirement of successful protection against overheating. In the following simulations it was assumed that during the day, between 9.00 and 21.00, ventilation air change is equal to 1 $h^{-1}$, and at night 4.0 $h^{-1}$. This volume of ventilation, far above indoor air quality requirements, should not be inconvenient for users in terms of the local velocity of air movement and associated noise. In EnergyPlus algorithm also additional requirements affecting the ventilation intensity are verified at each step. Air exchange will be completely shut off when the internal temperature drops below 22 °C, to protect users against too low temperature during night. It will be stopped also when the outside air temperature is higher than the temperature of indoor air. Very strict requirement imposed in this case on minimum temperature of internal air certainly reduces night cooling efficiency. In case of a well-designed and properly operated public facility used only during the day, intensive night cooling and low night temperature (e.g. 16 or 18 °C) would completely eliminate overheating.

Often reported problems with overheating and discomfort conditions in low energy buildings raised the serious questions regarding the negative effects of thick layers of thermal insulation. These doubts are based on a belief transferred directly from stationary conditions that effective thermal insulation blocks heat dissipation to the external environment and thus promotes the growth of the temperature inside the building.

Complete results of thermal comfort evaluation for reference case of the simulated building with 15 cm of thermal insulation, night cooling and double glazing are given in Table 2. Table summarizes for each separated zone and for the two considered acceptance levels number of hours during which the internal thermal conditions are beyond the adaptive comfort range, i.e. time not meeting the adaptive thermal comfort model. The big numbers of discomfort hours in the two southern zones IV and V are obviously the result of the large solar gains through not shaded windows with high solar radiation transmittance (transmission factor g = 0.724).

Tab. 2 Time not meeting the adaptive thermal comfort model [h] – 15 cm of thermal insulation

| Acceptance range | 90% | 80% |
|---|---|---|
| zone I | 194 | 55 |
| zone II | 94 | 3 |
| zone III | 194 | 55 |
| zone IV | 545 | 413 |
| zone V | 566 | 343 |

In case of zone V and high acceptance level, overheating covers over 25% of the total simulated period, while according to common practice 10% is maximum allowable duration. Some extra measures against overheating would be necessary in this building.

At the next step, thermal resistance of external walls was increased by means of 35 cm thick mineral wool. In the most overheated V-th zone discomfort duration was extended only to 575 h [9]. And finally in case of the massive brickwork structure without any additional thermal insulation layer, time not meeting the comfort criterion would be equal to 629 h.

General conclusion is that even significant increase of insulation thickness (15 to 35 cm) had no negative effect on the overheating time. Discharge of heat accumulated in building thermal capacity takes place to a large extent back to internal and not external environment.

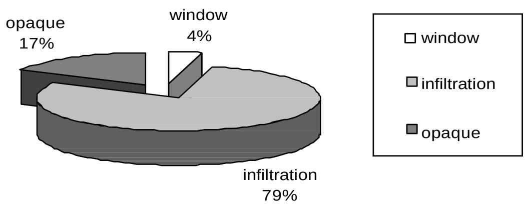


Figure 3. Zone V. Structure of the seasonal heat losses from the simulated space, 15 cm of thermal insulation

The above statement may be once more confirmed by the structure of the seasonal heat transfer from Zone V, Fig. 3. Share of conduction heat transfer to external environment through opaque part of the building shell is ca. 17%, while in case of 35 cm thermal insulation it would decrease to 16% of the total energy balance of this space. Efficient thermal insulation, necessary to reduce heat losses during winter, practically does not contribute to overheating intensity or duration.

## 5. Thermal storage versus thermal comfort

Influence of thermal stability of building on internal thermal comfort in summer was investigated at the next stage of simulation. In order to be close to building practice, all the massive walls of reference case building have been modified to the lightweight structures, consisting of mineral wool layer between the gypsum plates. Both the floors have been left unchanged, i.e. massive reinforced concrete structures with the specific floor layers. Final building enclosure is a mixture of the vertical lightweight walls and the massive horizontal floors.

The simulation results obtained for building with drastically decreased thermal capacity have been shown in Table 3. In all the sunny zones (I, III, IV and V) enormous increase of discomfort duration may be observed. In case of zone I and III overheating time was extended over 2 times (218%) and in case of zone V 1.5 times (149%). It should be emphasized that the simulated version of building was not “zero capacity case”. Beside massive ceiling, gypsum plates with large area contribute significantly to heat accumulation. However, in extreme summer conditions, i.e. solar gains combined with high external temperature, thermal storage capacity is not enough to absorb excessive energy and to prevent temperature build-up.

Tab. 3 Time not meeting the adaptive thermal comfort model [h] – 1ightweight building shell

| Acceptance range | 90% | 80% |
|---|---|---|
| zone I | 424 | 248 |
| zone II | 136 | 48 |
| zone III | 424 | 248 |
| zone IV | 798 | 599 |
| zone V | 841 | 639 |

An intermediate building version was analyzed to assess importance of thermal capacity of external walls only. In case of the lightweight external walls and massive internal walls discomfort time in Zone I was 214 and in Zone V 576 h. Comparing to Table 2, time not meeting comfort criterion was extended by 10% and 2% respectively.

Thermal capacity of building enclosure has a very significant impact on internal microclimate in unconditioned building. Massive building components may in a passive way prevent or at least reduce summer overheating. Significance of the external walls capacity is usually overestimated due to one-sided heat accumulation.

Presented above analysis was based on criterion of discomfort duration only, while importance of thermal storage is also connected with reduction of maximum temperature [9]. In a heavyweight building maximum summer temperature was ca. 5 K lower than in a lightweight one.

## 6. Summary

Designer has at his disposal a few simple "passive" solutions that can be used to control thermal comfort conditions in building in order to avoid or reduce active cooling.

A very important and at the same time difficult task is a rational design of glazed openings in the building. They largely affect the subsequent thermal conditions in the building and demand on heating and cooling. There is no one simple rule of thumb for window sizing. In each case an advanced computer modeling should be done in order to minimize total demand on energy. Apart from this, glazed openings must be equipped with a shading system in form of overhangs, shutters, fixed or movable shading elements, glazing with variable properties etc.

Very effective measure against overheating, that requires a relatively small amount of conventional energy is night cooling i.e. intense cooling of a massive enclosure during the night.

There is no negative impact of thermal insulation of the building external shell on internal microclimate. Even very thick layers of thermal insulation, typical for zero energy buildings, do not intensify overheating duration.

The massive building components with very high thermal capacity provide very effective passive protection against overheating and excessive fluctuations of temperature. Heat storage in internal walls is especially effective due to big area of surface heat transfer.

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